DE LA RECHERCHE À L'INDUSTRIE

CEA EXPERIENCE OF LOW BETA CRYOMODULES

N. BAZIN

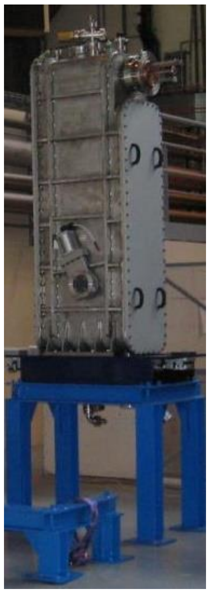
TTC Meeting

MSU – February 2017

www.cea.fr

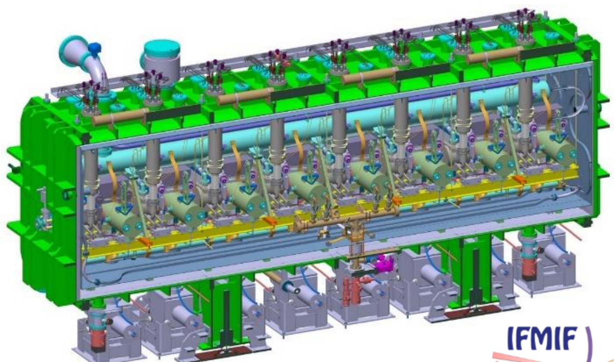
CEA EXPERIENCE ON SUPERCONDCUTING LINAC

Booster → MACSE → SOLEIL TTF, SLS → SPIRAL2 XFEL → IFMIF EVEDA → ESS, SARAF → IFMIF DONES → Futur

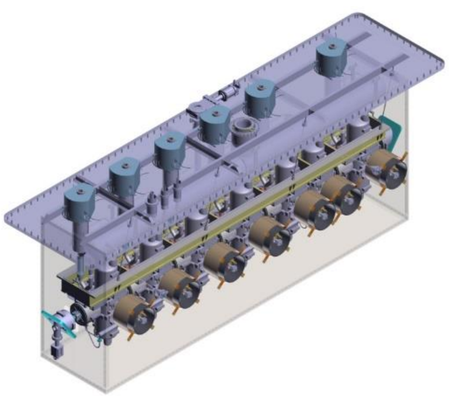


SPIRAL2: design and assembly of 12 cryomodules

XFEL: assembly of 103 cryomodules (1 CM/wk)



IFMIF LIPAc: 1 cryomodule



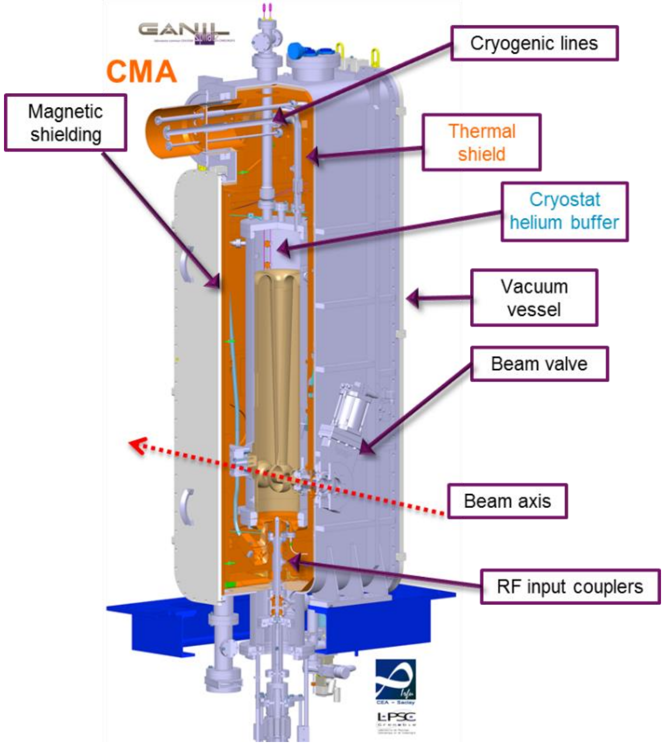
SARAF Phase2: 4 cryomodules

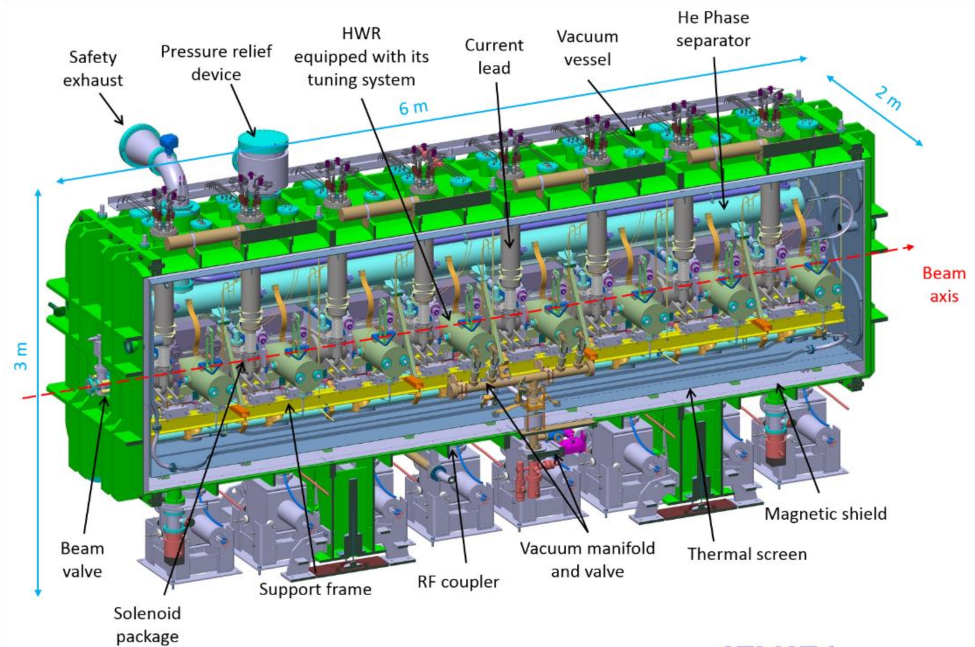
ESS: cavity and coupler design, integration of 30 cryomodules

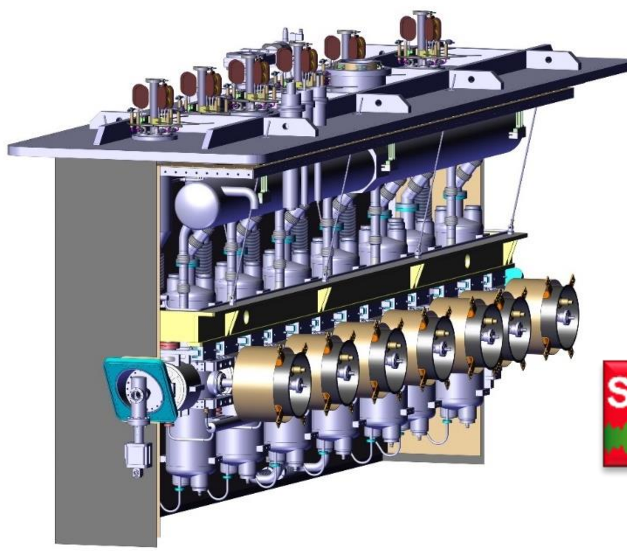
THE LOW BETA CRYOMODULES @ CEA SACLAY

	Spiral 2	IFMIF-EVEDA	SARAF		IFMIF-DONES		
	CMA		CM1 & CM2	CM3 & CM4	CM1	CM2	CM3 & CM4
Number of cryomodules	12	1	2	2	1	1	2
Status	Installed on beam line, ready for commissioning	Being manufactured	Preliminary design phase		Conceptual design phase - layout of the superconducting linac to be confirmed by beam dynamic group		
Number of period per cryomodule	-	8	-	-	8	5	4
Cavities per cryomodule	1	1x8	6 (7)	7	1 x 8	2 x 5	3 x 4
Solenoids per cryomodule	-	1x8	6	4	1 x 8	1 x 5	1 x 4
Cavity							
Type	QWR	HWR	HWR	HWR	HWR	HWR	HWR
Frequency (MHz)	88	175	176	176	175	175	175
β	0.07	0.094	0.091	0.181	0.094	0.094	0.166
E_{acc} nomimal (MV/m)	6.5	4.5	6.5	7.5	4.5	4.5	4.5
Power coupler							
Power (kW CW)	12.8	70 (designed for 200 kW)	10	20	LIPAc coupler: 200 kW		
Superconducting solenoid							
Maximum magnetic field (T)	-	6	5.8	5.8	LIPAc solenoid: 6T		

THE LOW BETA CRYOMODULES @ CEA SACLAY

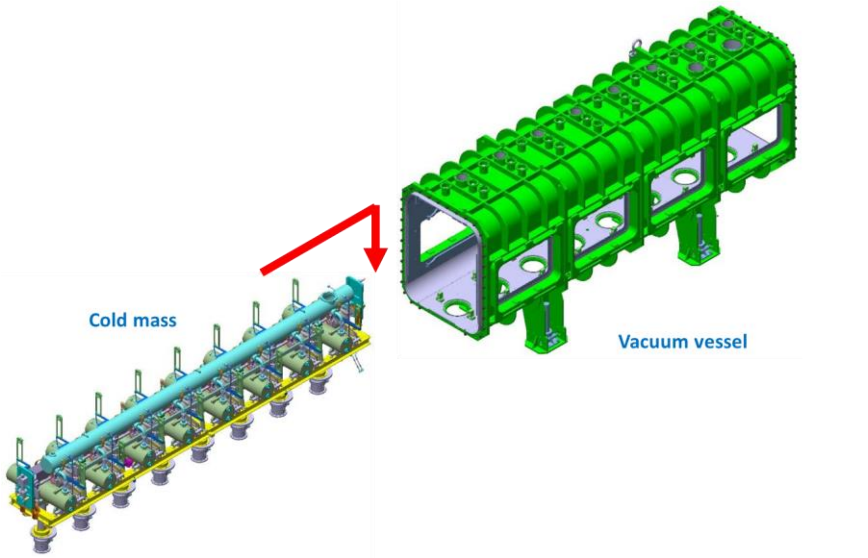


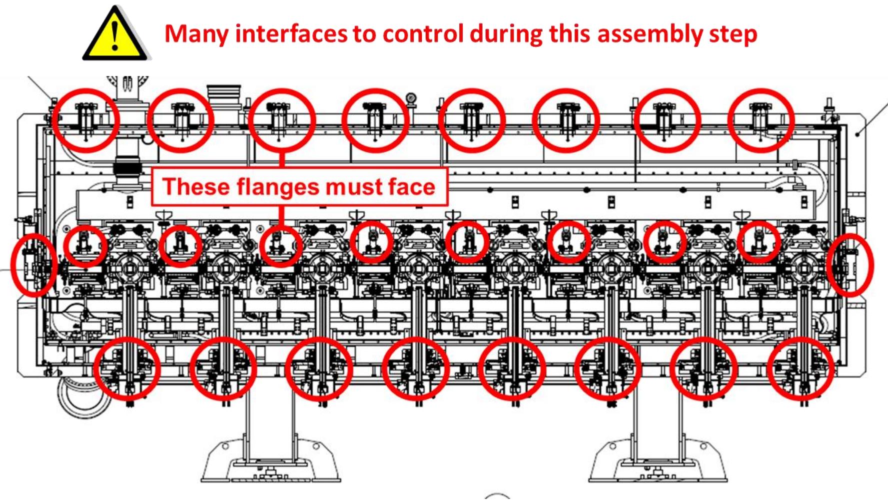




IFMIF-LIPAC: SIDE LOADED CRYOMODULE

- Configuration set at the beginning of the design phase
- Due to the couplers, the cold mass must be inserted in the vacuum vessel in two steps:
  - Horizontal sliding of the frame which is higher than its final position. The frame should be set up so that the couplers are facing the flanges of the vacuum tank.
  - Vertical motion of the frame until the coupler flanges touch the vacuum tank flanges.
- During the insertion of the cold mass, the operators have to be sure that every interface flange of the power couplers properly mates with its corresponding flange (same for the flange of the pumping line).
- The operators have also to check that the interface flange between the solenoid and the current lead package faces its corresponding flange of the vacuum vessel, and that he interface flange of the beam valves faces its corresponding flange of the two doors.
- Tools used for the operation have to be removed without damaging the components of the cryomodule (small space).
- Many assembly steps have to be performed after the insertion of the cold in the vacuum vessel, with small access room for some operations (example: welding of the solenoid package wires to the current lead busbars).



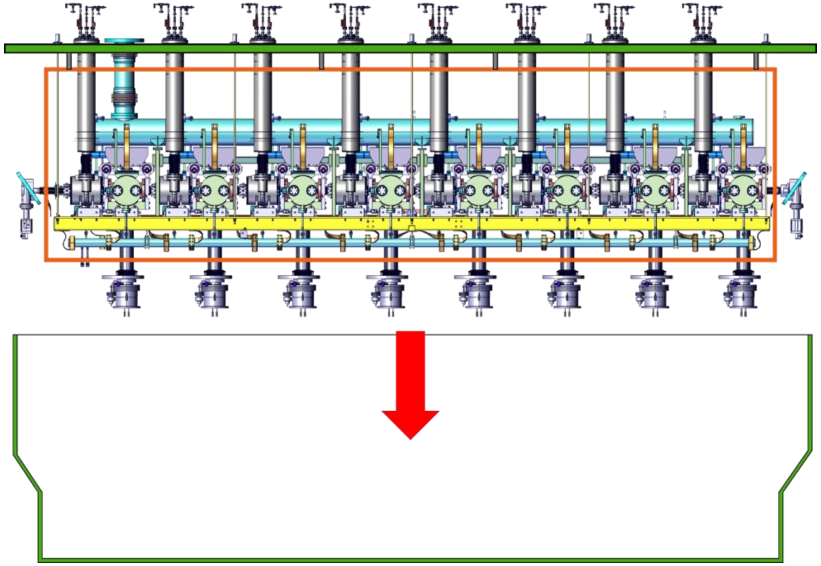


IFMIF-DONES: TOP LOADED CRYOMODULE

- IFMIF-DONES cryomodules may be longer than IFMIF-LIPAc one:
  - If side loaded cryomodule: insertion rails bigger to avoid cold mass bending during insertion in the vacuum vessel → space should be left for these ones → has been difficult for the LIPAc cryomodule
  - It seems inappropriate to use the same assembly process

IFMIF-DONES conceptual design: top loaded cryomodule

- As all the interfaces but the power couplers and the beam valves are with the top plate, the assembly process is simpler.
- Most of the work could be performed before the insertion in the vacuum vessel:
  - Completion of the helium circuitry with leak and pressure tests
  - Installation of the current leads
  - Cabling of the sensors and actuators
  - Installation of the multi layers insulation blankets
  - Installation of the thermal shield with leak and pressure tests

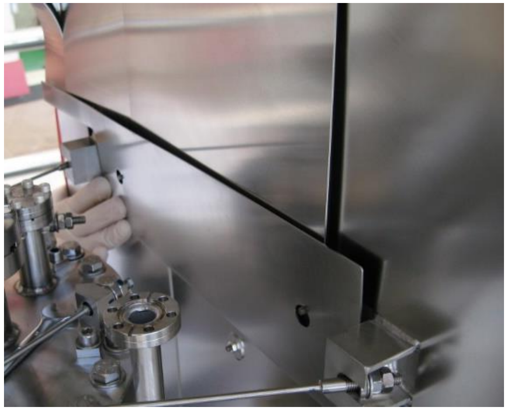


Top loaded design also used for SARAF cryomodule

MAGNETIC SHIELD: SPIRAL 2

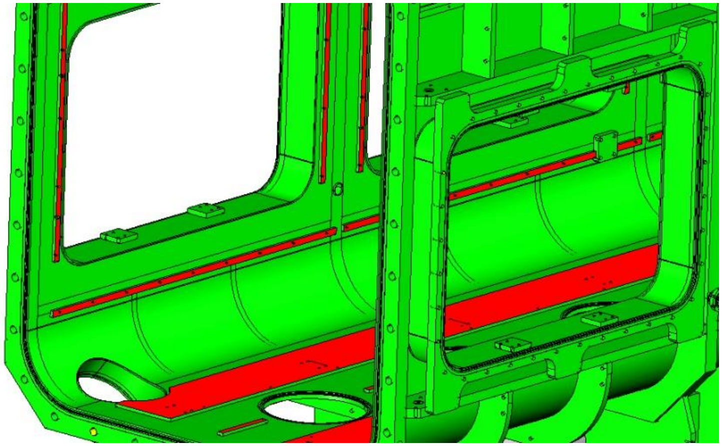
- ❑ Global magnetic shield
- ❑ Panels directly installed on the inner surface of the vacuum vessel
- ❑ Complex design because of the cavity already installed in the vacuum vessel
- ❑ Difficulty to assemble because of the manufacturing defects of the components

The Spiral2 cryomodule before the assembly of the magnetic shield



MAGNETIC SHIELD: IFMIF-LIPAC

- Global magnetic shield
- To avoid assembly problems like for Spiral 2, panels installed on the baseplates and rods with threaded holes and welded on the inner surface of the vacuum vessel
- The interfaces holes had to be precisely positioned → severe requirement for the manufacturer
- Minor manufacturing defects of the vacuum vessel → some threads had to be reworked and some holes had to be enlarged after the blank assembly of the magnetic shield panels in the vacuum vessel before heat treatment

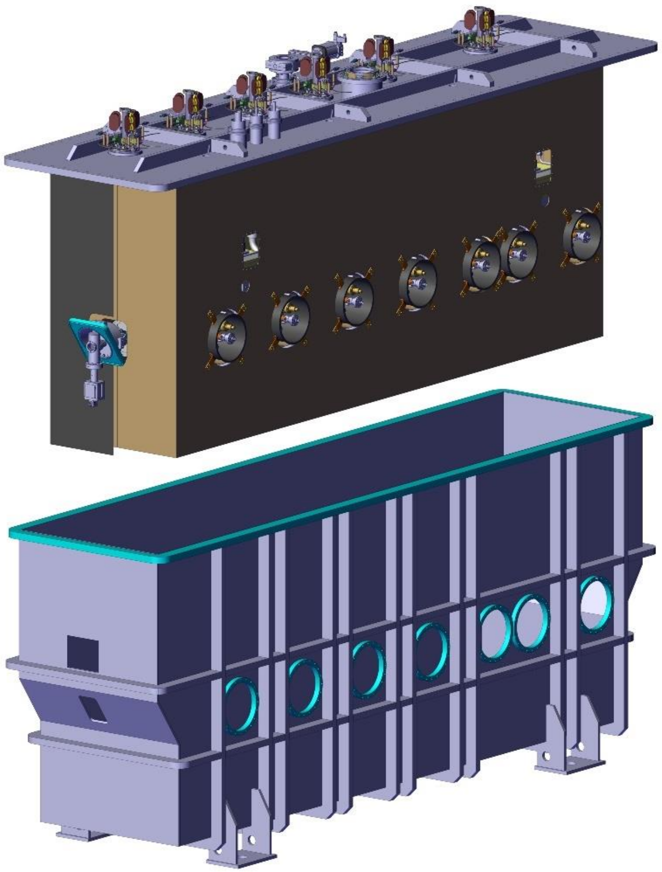


In red, interfaces of the vacuum vessel with the magnetic shield

Inside of the vacuum vessel

Magnetic shield installed in the IFMIF-LIPAc cryomodule

MAGNETIC SHIELD: SARAF



- Global magnetic shield
- To avoid manufacturing constraints like for IFMIF-LIPAc cryomodule, panels are not anymore in contact with the inner surface of the vacuum vessel, but floating between the vacuum vessel and the thermal shield (covered by multi layer insulation)
- Estimated shield temperature: 3K below room temperature → no impact of mu-metal magnetic performances
- Magnetic shield connected to the top plate of the vacuum vessel

CLEAN ROOM: ISO4 OR ISO5?

What should be the clean room class for assembly low beta cryomodule?

Experience of Spiral 2

- Test values shown in the table below
- Both the ISO 4 and ISO 5 assemblies, the cryomodule design was the same, the clean room operators were the same and the same assembly procedure was followed
- The accelerating field gradient E_{acc} always exceeds the specification (6.5MV/m)
- The X-ray emission figures are always low in the ISO 5 assemblies – worse values were measured in the ISO 4 cases → improvement of the assembly steps from one cryomodule to another, gain of experience of the operators

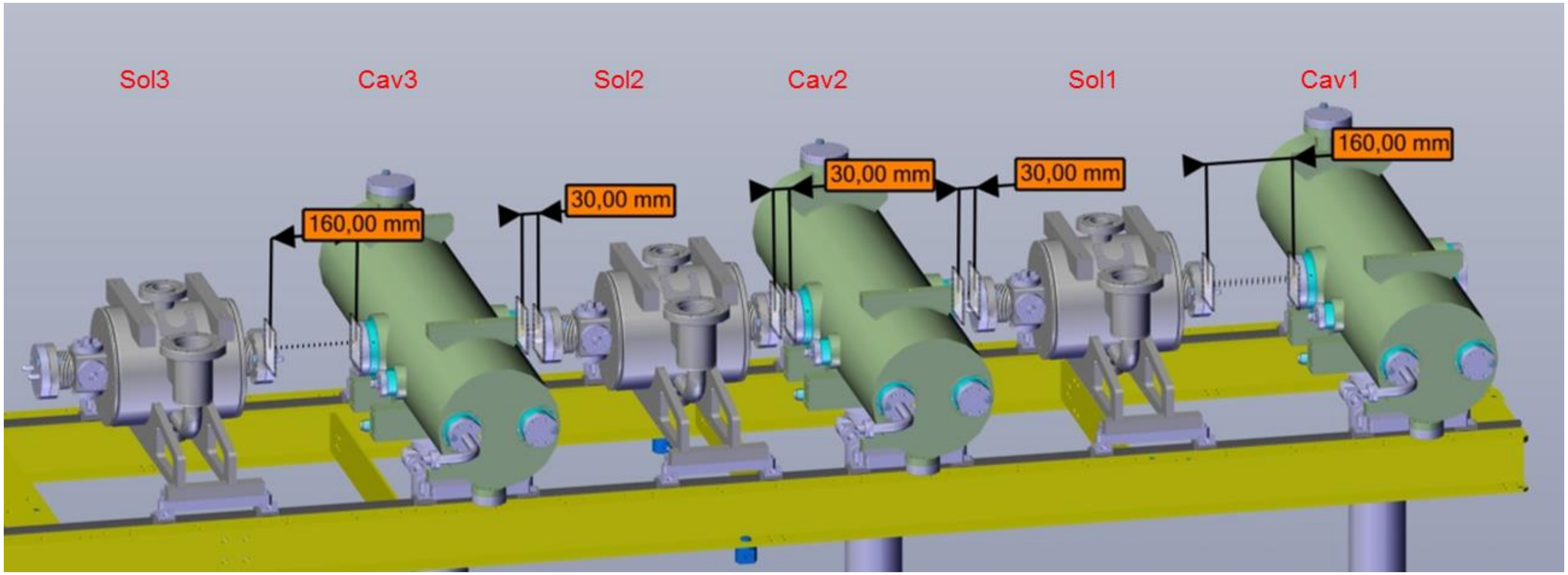
	Unit	Specs	CMA4	CMA6	CMA7	CMA2	CMA3	CMA5	CMA9	CMA8	CMA10	CMA12	CMA1	CMA11
Eacc max	MV/m		8,85	8,34	9	8,6	7,95	9,1	8,44	9	9,11	7,8	9	9,07
total losses @7.8MV	W		41,5	22,6	14,1	42,7	40,8	18,9	36,7	18,88	16,31	17,64	18,75	22,88
total losses @5.5MV	W			7,5	6,5	9,05		7,43	non mes	7,51	7,25	9,06	10,1	9,3
Static 70K	W		22	25,4	22,87	25,86	28,5	30,71	33	28,46	30,45	25,1	24,75	20,8
X Rays @6.5MV/m	µSv/h		560	91	14,3	730	494	1,5	677	32	3	2,2	19,7	1

Assembled in ISO 4 (CMA4 – CMA8) | Assembled in ISO 5 (CMA10 – CMA11)

→ Class of the clean room has no impact on the cryomodule performances

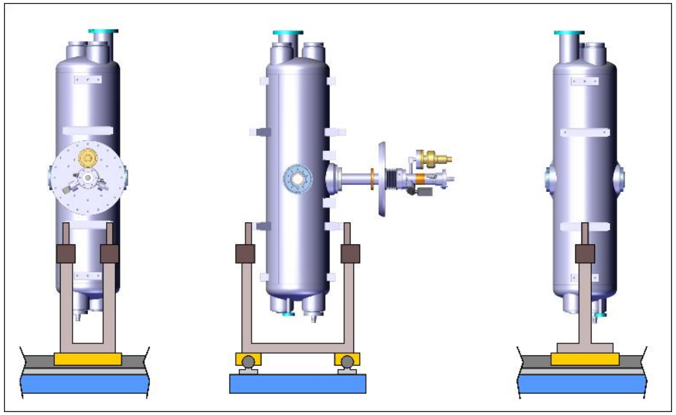
IMPROVEMENT OF THE ASSEMBLY PROCESS - 1

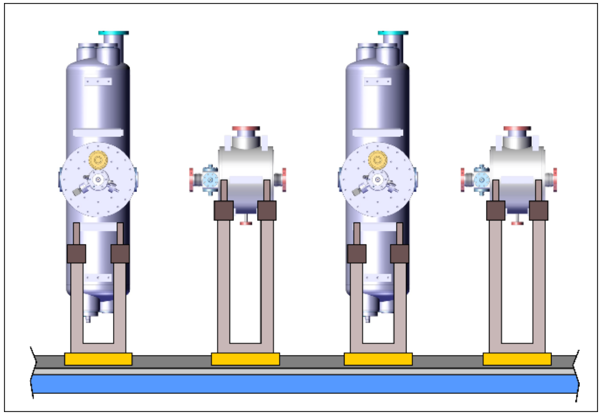
- LIPAc cryomodule: the titanium frame is used as support of the cavity string in clean room →severe requirements on the manufacturing:
  - For clean room reasons, all the surfaces of the I-beams are machined before welding
  - After welding, the top surface of the frame are precisely machined (flatness requirement: 0.1 mm/m)
- The minimum distance between the flanges of a solenoid and a cavity is 160 mm for a safe removal of the flanges used to position the components → constraints on the motion of the elements along the frame due to the vertical power couplers and the strengthening bars

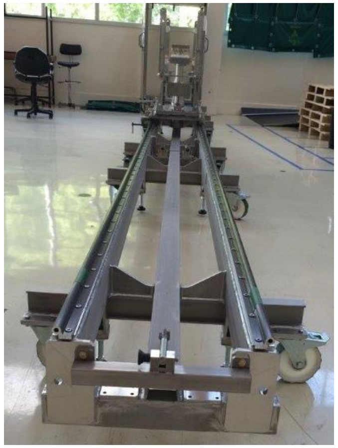


IMPROVEMENT OF THE ASSEMBLY PROCESS - 2

- SARAF cryomodule: The frame is not used in clean room, but a trolley with rails and positioning post (as for XFEL and ESS cryomodule)

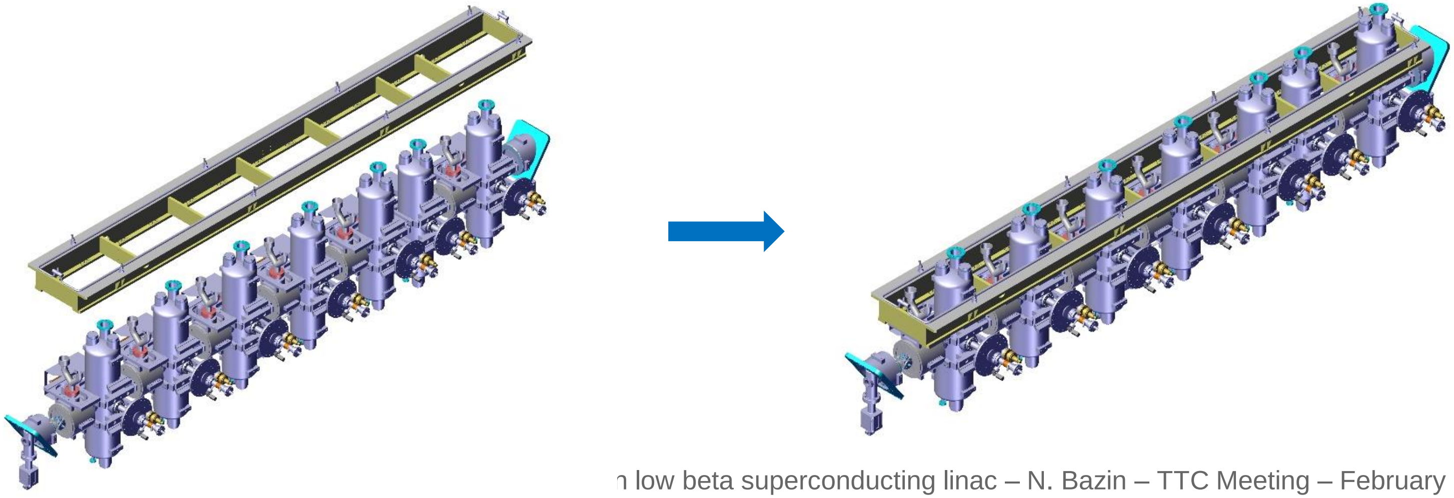






Cavity string assembly support for ESS ECCTD

- Assembly of the cavity string to the frame outside the clean room



SUMMARY

- CEA has gained a lot of experience in low beta cryomodule design and assembly over the last two decades

- Improvements were implemented in cryomodules, not only the ones presented here but also in magnetic hygiene, thermal shield and vacuum vessel design, heat sinking …